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Replacing fossil fuels with biomass at the central power plants

Peter Glarborg

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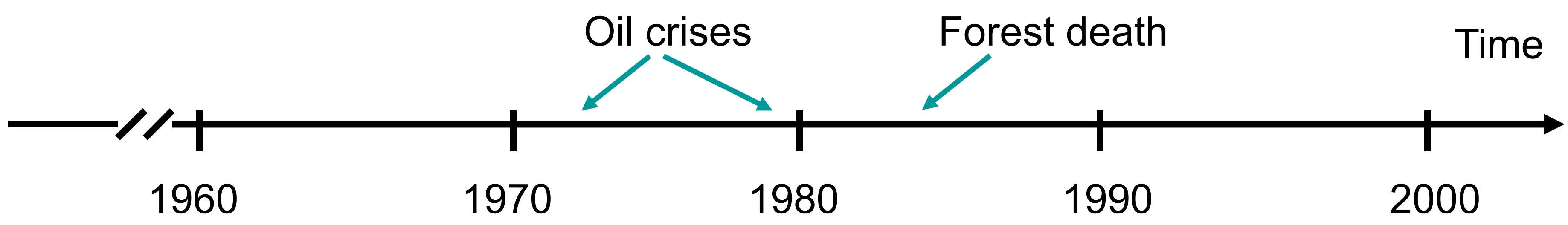
Department of Chemical and Biochemical Engineering

Engineering challenges in the power industry

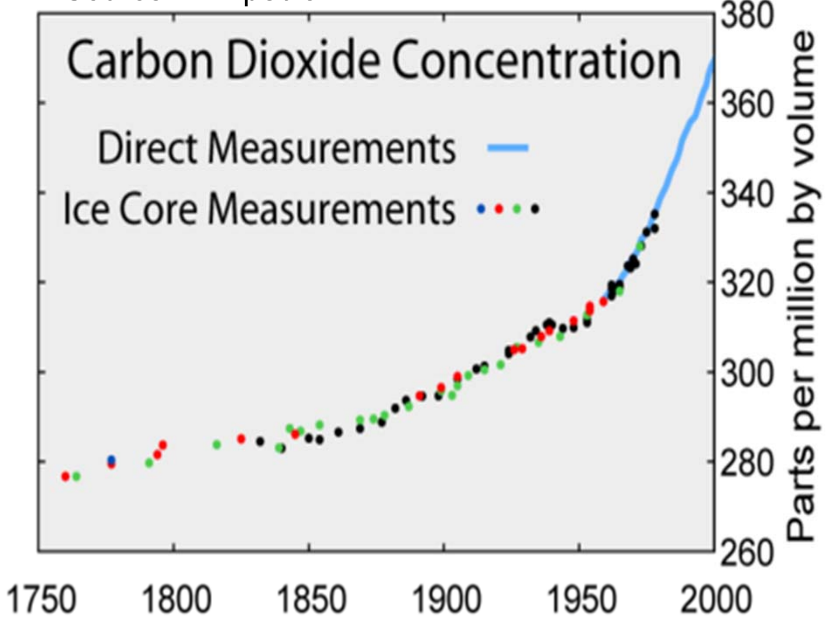


Coal	Oil	Coal	Range of fuels
Extension of power distribution	Large mechanical constructions	Expansion	Environment Decentralization Deregulation Fuel flexibility

Dam-Johansen (2000)

Current challenges for the power sector

Source: Wikipedia



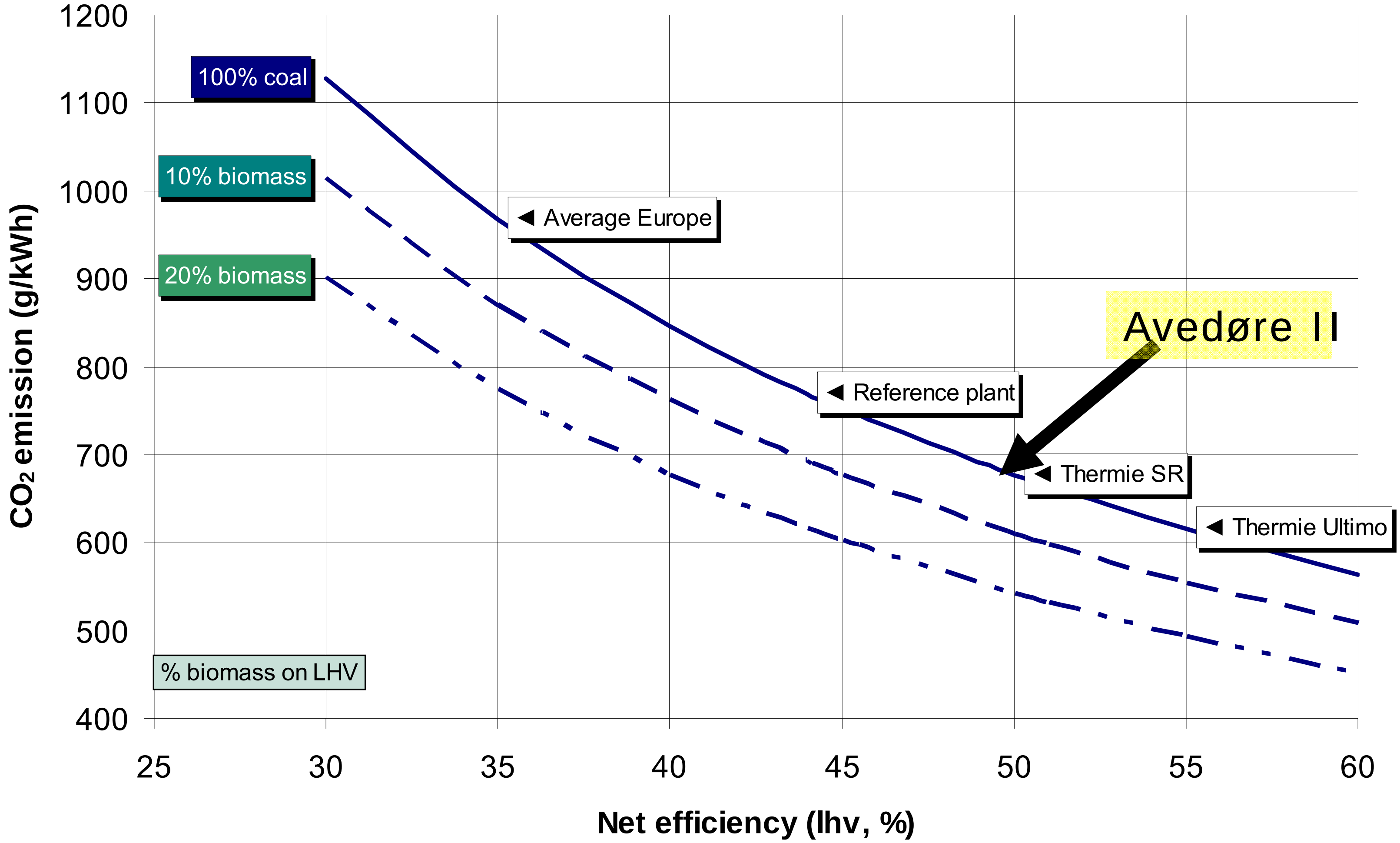
Targeting sustainability

- 2020
- 2050

Current power supply

- Wind turbines
- Hydro power
- Solar power
- Thermal power plants
  - Required for balancing
  - Supply district heating
  - Mainly based on coal
  - Challenges
    - Conversion to biomass
    - Flexibility (load, fuel)
    - Electrical efficiency
    - Financial sustainability

Efficiency and biomass share versus CO_2



Bo Leckner, CTH

Biomass Fuels in Europe

- Woody biomass fuels:
  - Bark
  - Industrial wood chips
  - Sawdust
  - Forest wood chips
  - Waste wood
  - Pellets, briquettes
- Herbaceous biomass fuels:
  - Straw, cereals
  - Grasses (miscanthus, giant reed)
- Alternative biomass fuels:
  - Kernels, shells, olive stones, shea nuts

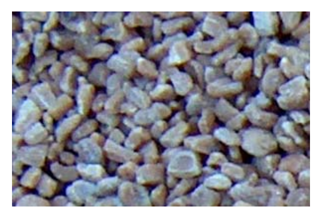




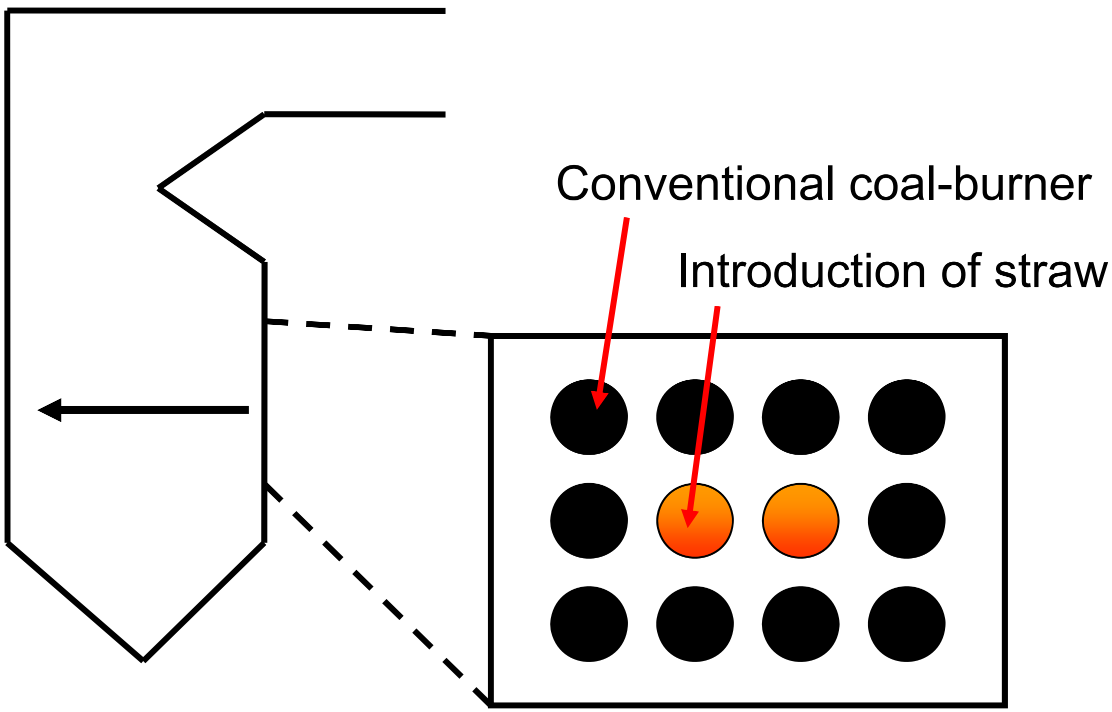






Use alternative fuels on power plants



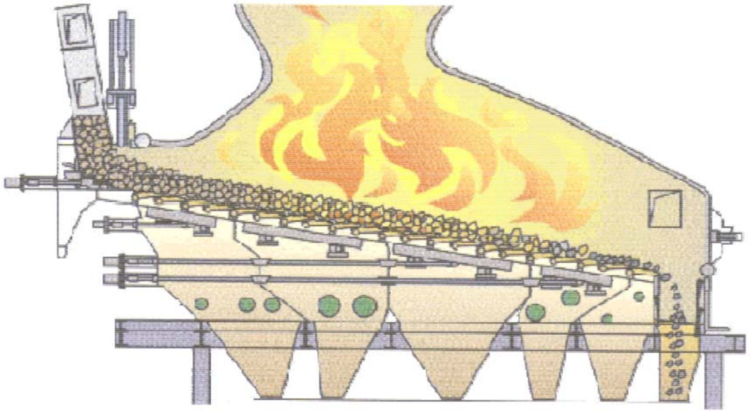
Central power plants

Present:
High electrical efficiency
Low fuel-flexibility

Vision:
100% fuel flexibility
Retain electrical efficiency

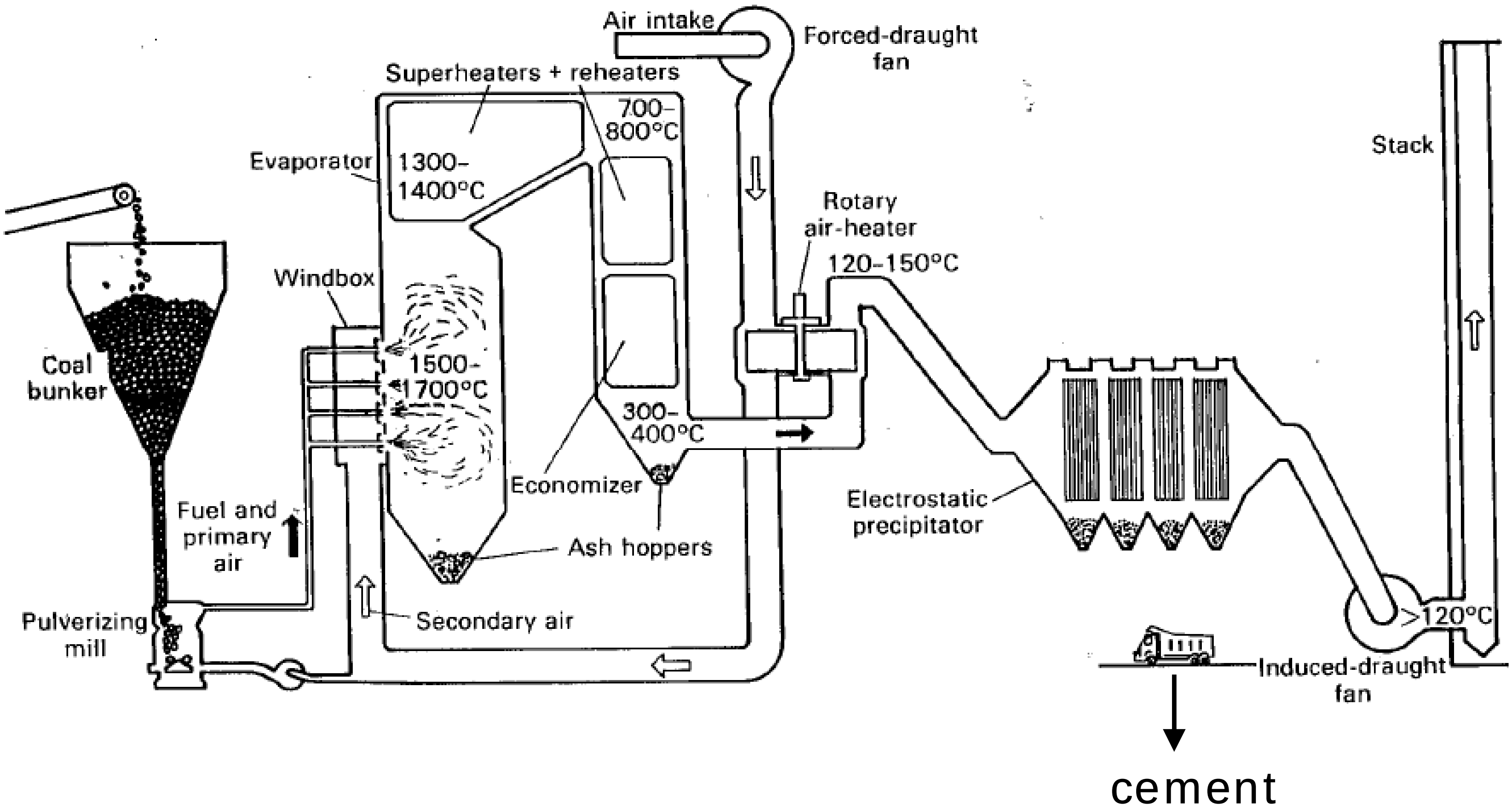
Decentral CHP plants

Present:	Vision:
High fuel-flexibility	High electrical efficiency
Low electrical efficiency	Retain fuel-flexibility

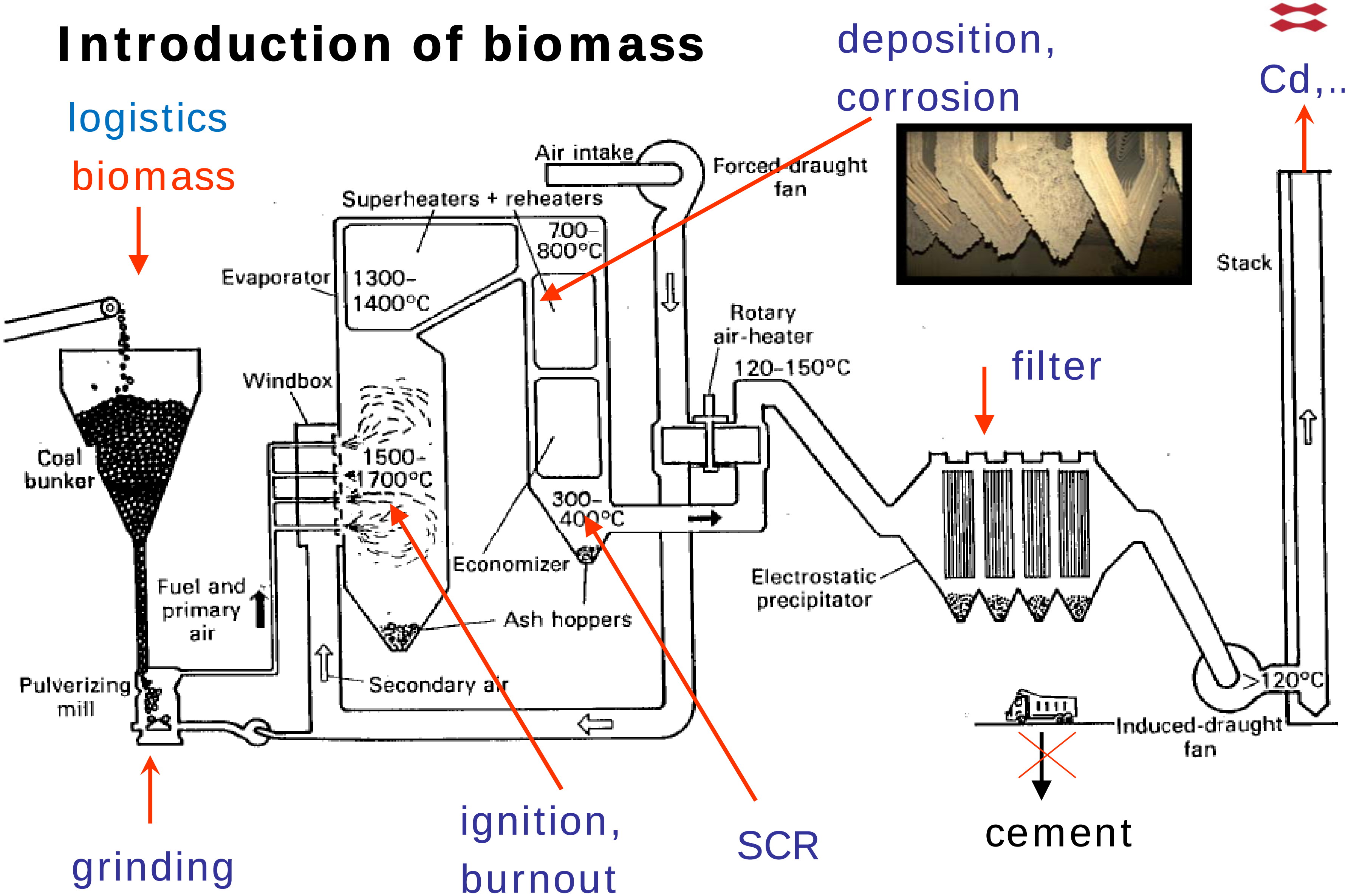


Nightmares of a plant operator

Diagram of coal-fired power plant



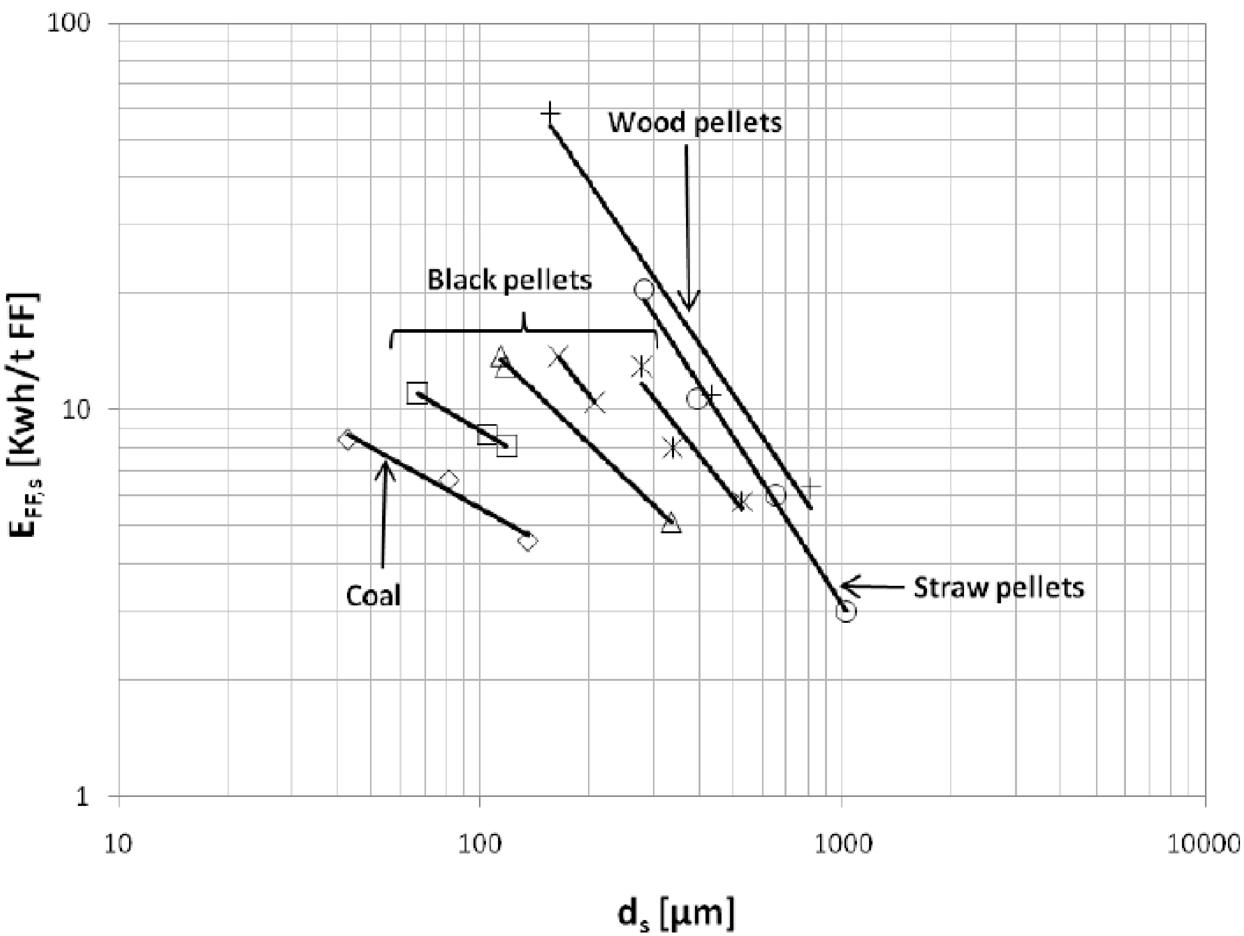
Introduction of biomass



Solid Fuel Characteristics

Fuel	Water content (Wt %)	Heating Value (MJ/Kg)	Density (Kg/m^3)
Straw	15	14 – 15	100
Straw + grains	15	14 – 15	200
Grains	15	15	700
Straw pellets	8	16	600
Wood chips	40	10 – 11	200 – 300
Saw dust	20	15	160
Wood pellets	6	17 – 18	660
Coal	10	25 - 28	800 - 1000

Grindability of solid fuels



Wadenback and Røjbæk, 2010

Bio-dust combustion

Differences in properties to coal:

- Particle size and form
- Pyrolysis behavior
- Char reactivity

Fuel conversion aspects:

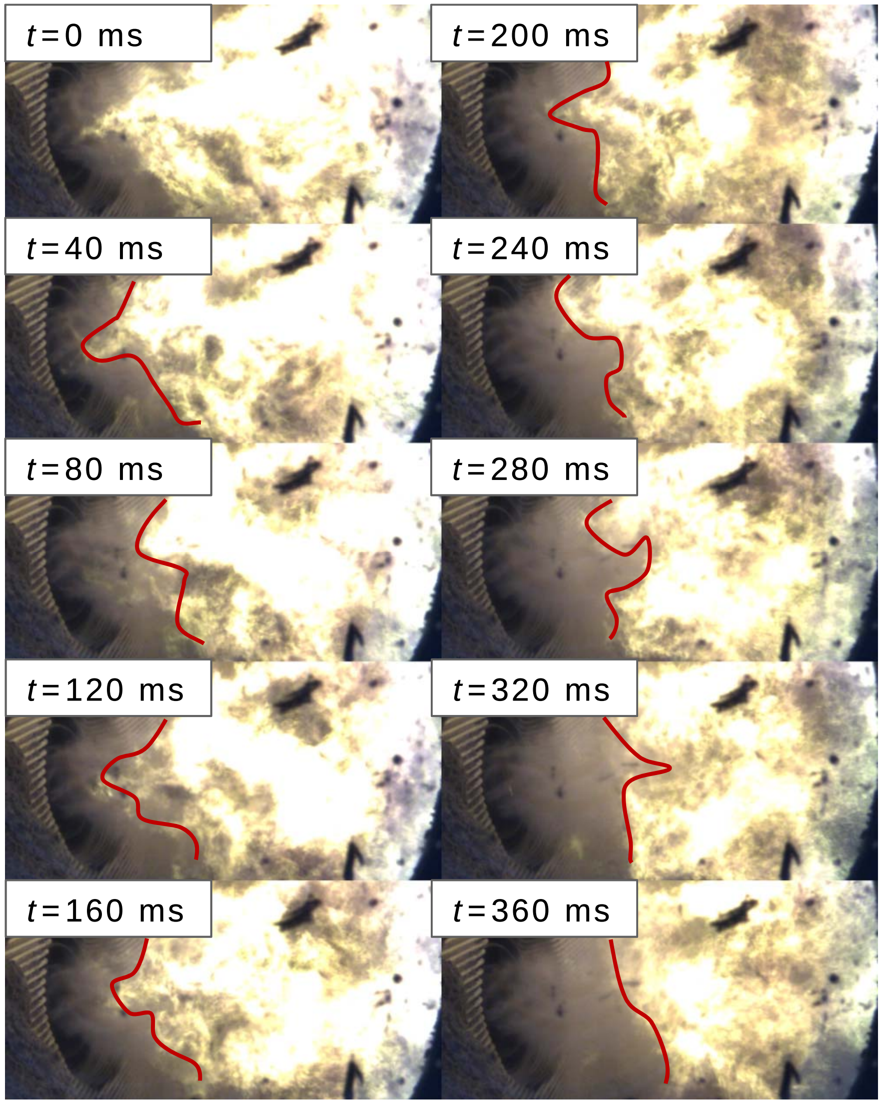
- *Ignition, flame stability*
- Energy release profile
- NO formation
- *Burnout*

Critical:

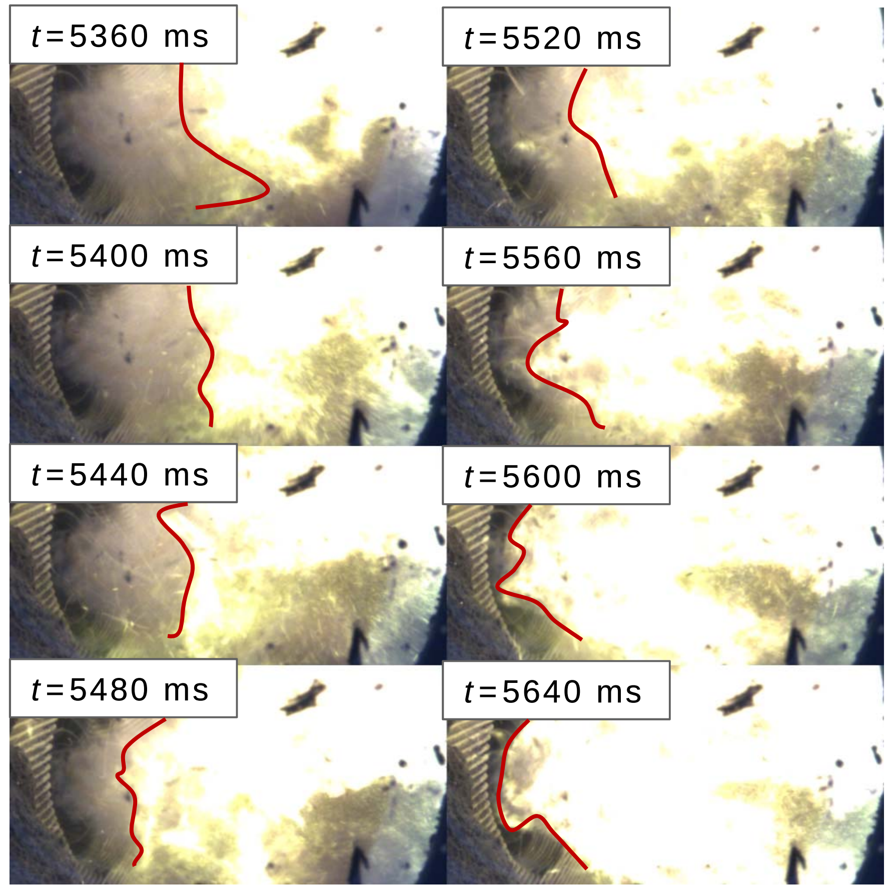
- Burner design
- Fuel quality
- Particle size distribution

Wood burner flame seen from above

AMV1: Flame attachment

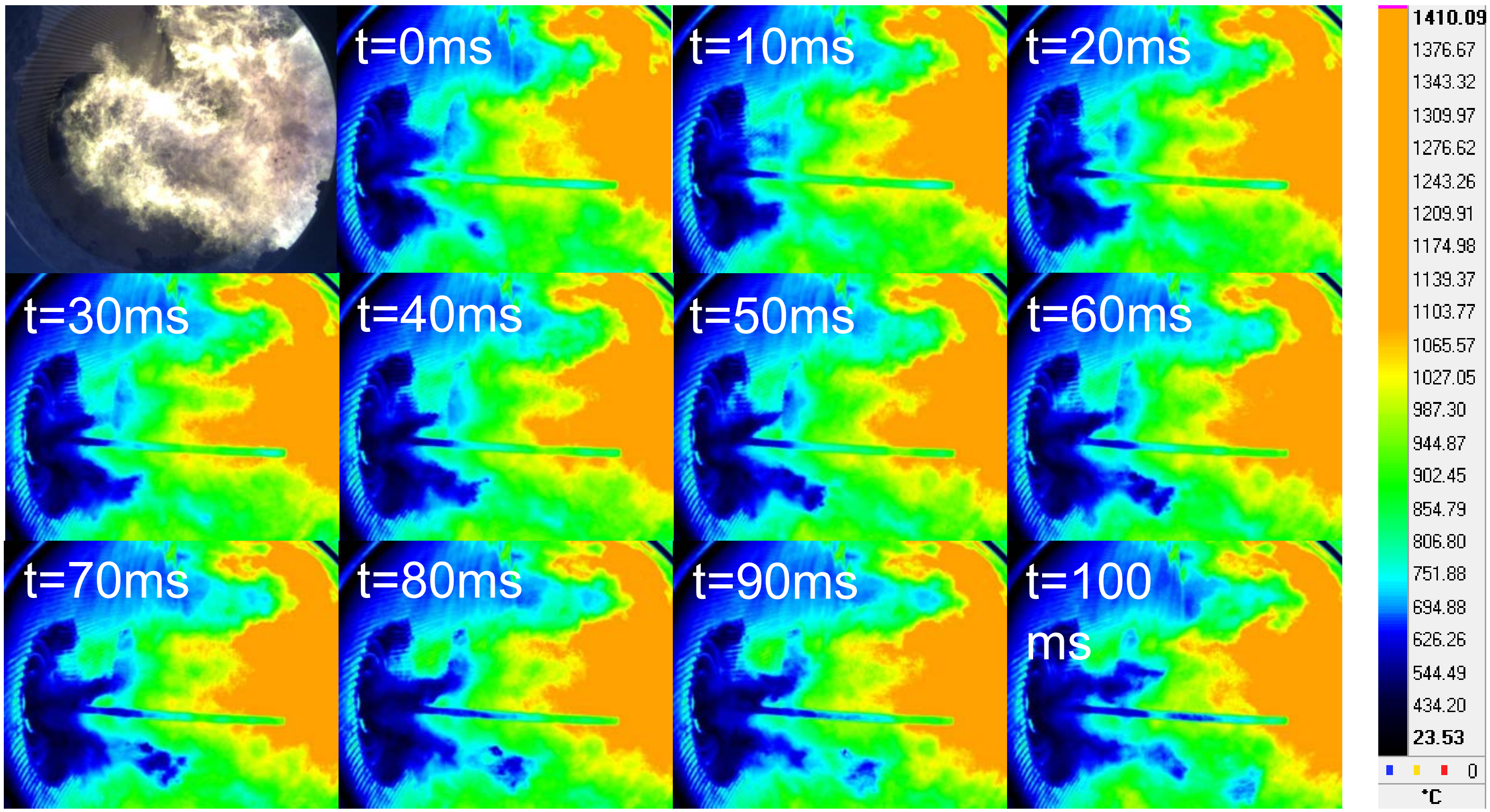


- Flame detachment and re-attachment
- 1 m flame lift
- Stable for several seconds



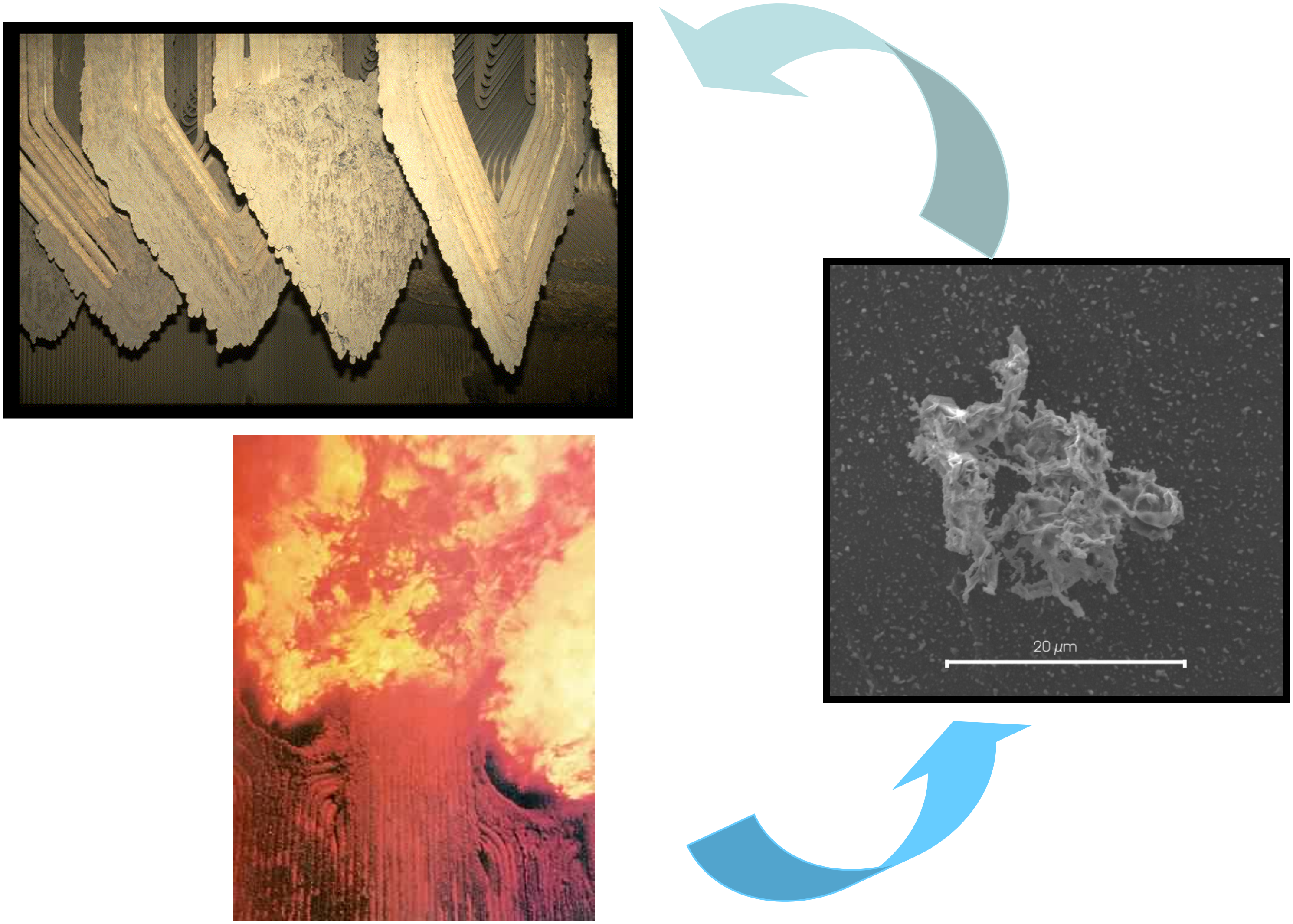
Johansen et al., 2013

AMV1: Temperature from optical diagnostics

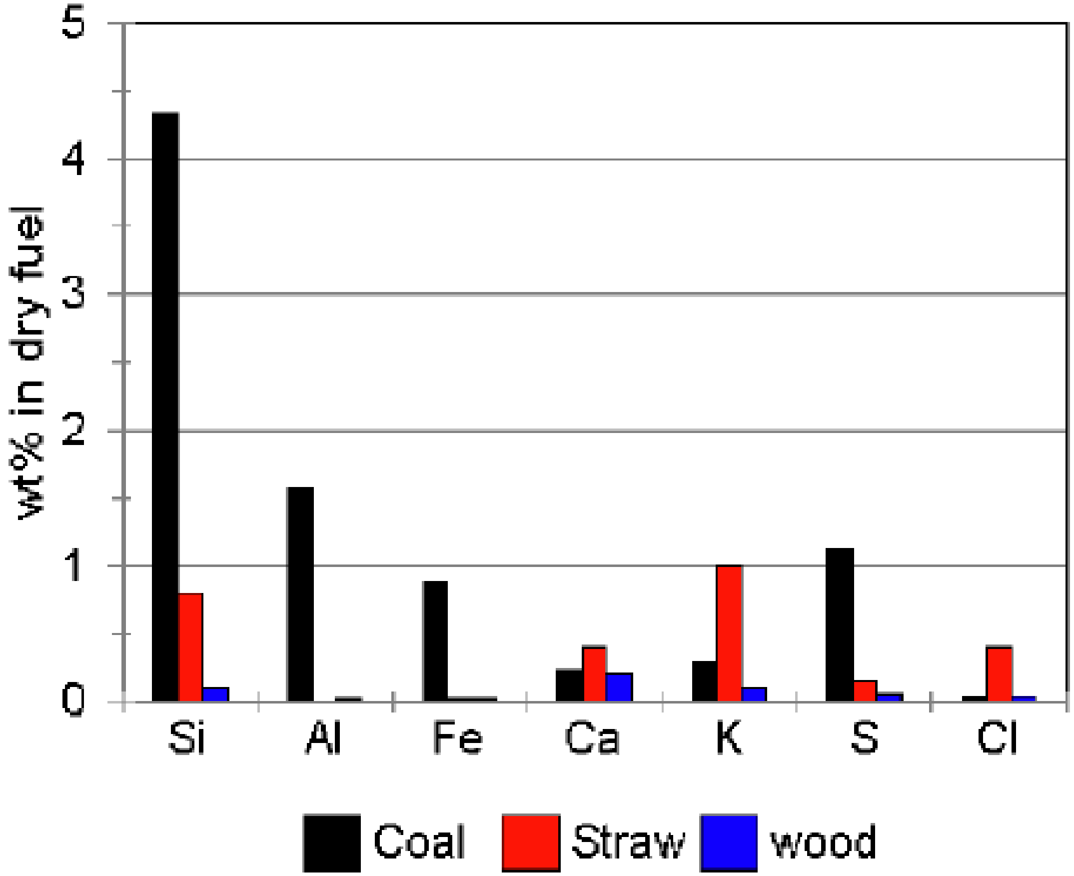


Johansen et al., 2013

The major challenge: the inorganic elements

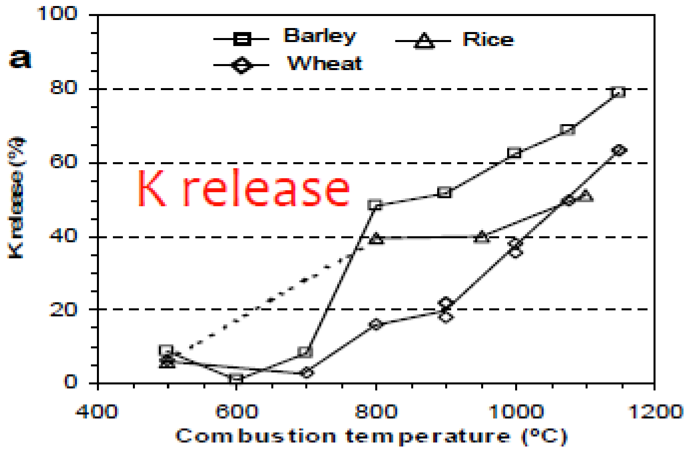


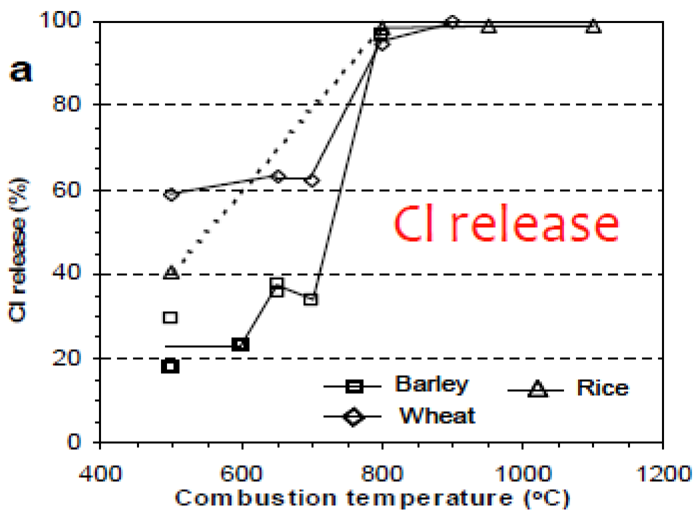
Ash generating elements – typical levels

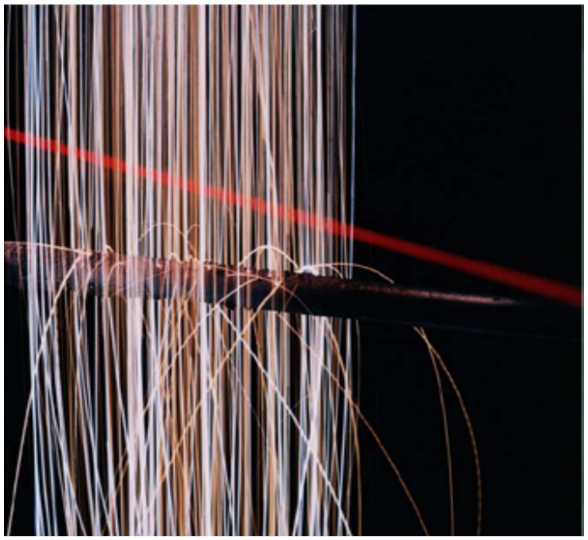


Dam-Johansen

High K+Cl content: Sticky and corrosive ash

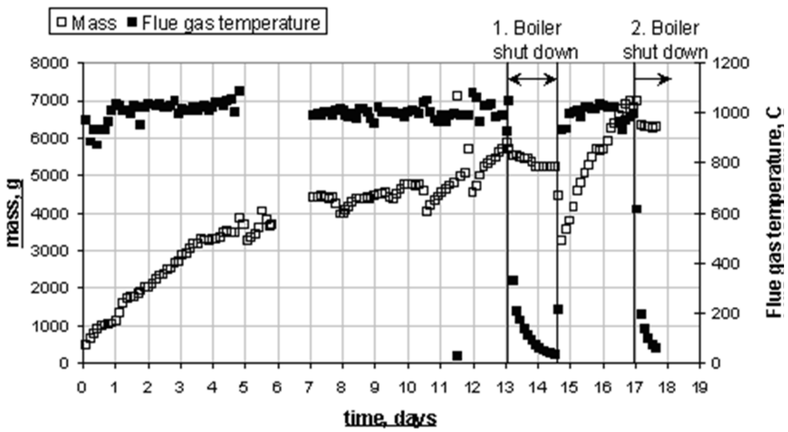






Deposition

Corrosion



The big chemical scoop of coal-straw co-firing:

+

Ash: $\longrightarrow$ Fly ash:

Al, Ca, Fe, K, Mg, Na, Si — K-Al-Si, K_2SO_4

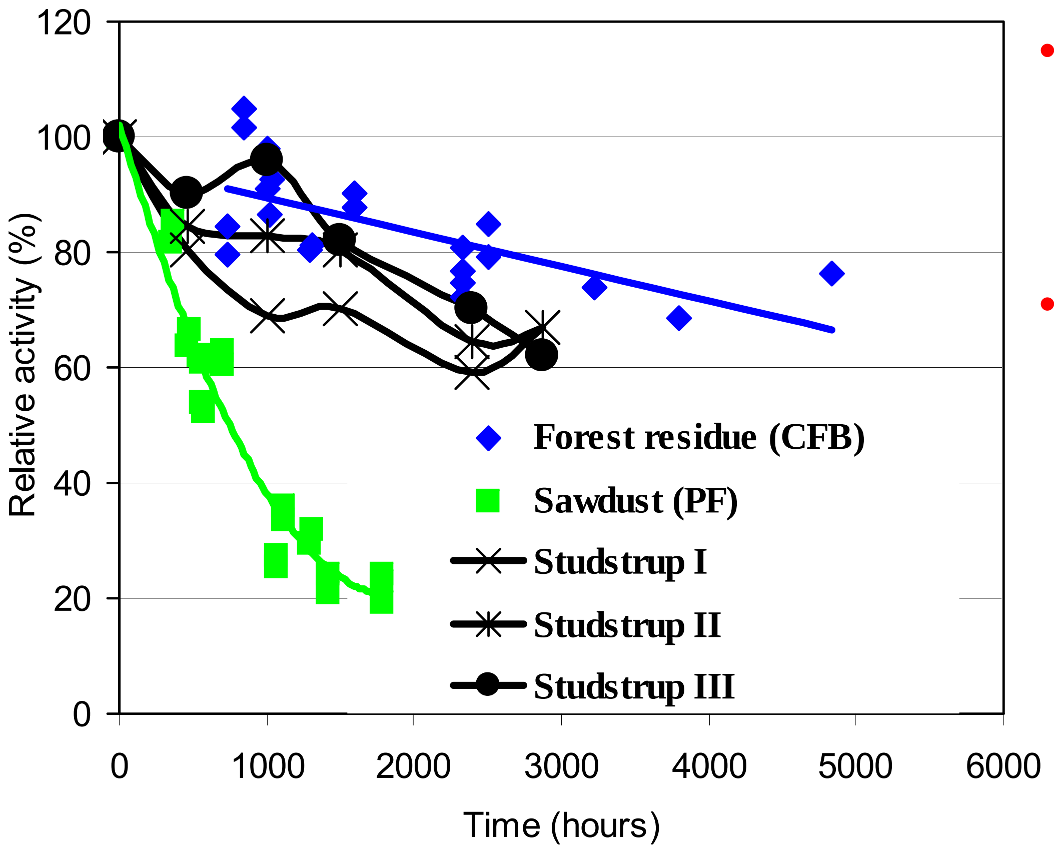
$\uparrow$ K

Ash: $\xrightarrow{Cl}$ HCl(g)

K, Cl, Si

F. Frandsen

Biomass combustion: SCR catalyst deactivation



Khodayari et al. (2000) and
Wieck-Hansen et al. (2000)

- Biomass is increasingly used for heat and power production alone or with other fuels
- Accelerated deactivation of SCR catalysts has been observed when firing biomass

Potassium speciation in ash: concerns

	Deposition	Corrosion	SCR deactivation	Fly ash quality
KCl	XXX	XXX	XXX	XXX
K_2SO_4	XX	X	XXX	
K-silicates	XX			
K-alumina-silicates	X			

- Deposition and corrosion: High K+Cl fuels → low superheater temperatures → low electrical efficiency
- Fly ash quality: biomass share in co-combustion with coal ≤20% for use in concrete production

GREEN:
Power Generation from Renewable Energy

Funding: DSF

Budget: >50 million DKK

Center leader: Peter Glarborg

Coordinator: Jytte Boll Illerup

- Biodust combustion on central power plants – issues:
  - Fuel availability and quality
  - Handling and pretreatment
  - Combustion process
  - Deposition and corrosion
  - Flue gas cleaning technology
  - Solid residue
- Disciplines
  - Agricultural science
  - Materials science
  - Thermodynamics
  - Fluid dynamics
  - Combustion chemistry
  - Catalysis
  - Inorganic chemistry

The GREEN Research Center

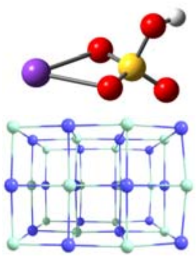
- Objectives: to facilitate an efficient conversion of coal-fired power plants to biomass, retaining a high electrical efficiency with a broad fuel-band
- Partners:
  DTU Chemical Engineering, DTU Mechanical Engineering, Aarhus University
  B&W Energy, DONG Energy, Vattenfall
  Stanford University, Lund University, HNE Eberswalde, University of North Texas
- Associated partners: Clausthal University, Haldor Topsøe
- Schedule: 2011-2015

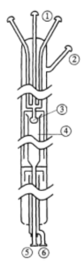
GREEN Work Packages

- WP1 Agricultural biomass quality (AU with HNEE)
- WP2 Fuel characterization (KT with SU, LU, VF, and DEP)
- WP3 Burner design (KT and Risø with BWE, VF, and DEP)
- WP4 Ash transformation, deposition and additives (KT with LU, UNT, VF, and DEP)
- WP5 Model based development and testing of advanced corrosion resistant super-heater materials (MEK with KT, DEP and VF).
- WP6 Deactivation of SCR catalysts (KT with DEP and VF)
- WP7 Utilization of ash as fertilizer (AU)

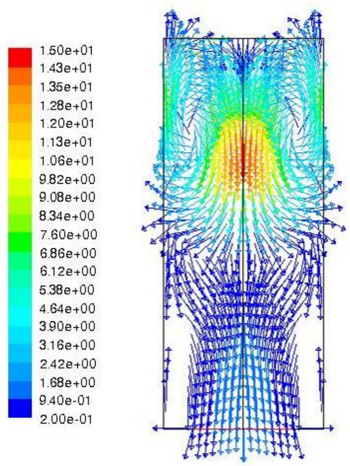
From molecular science to advanced technology

Semi-industrial scale experiments



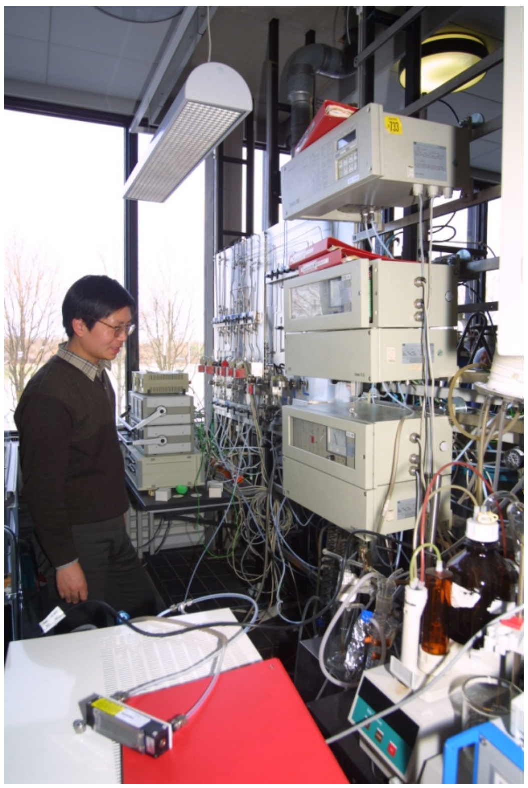


Model (CFD)



How do we work

Laboratory experiments



Pilot scale measurements

Full scale measurements

Model development

Concluding remarks: biomass for power

- Denmark worldwide leader in biomass for power and heat since early 1990's, facilitated by strong RD&D efforts
- The Danish power supply structure in rapid transition, imposing needs for adaption of current thermal technologies to biomass
- Short term needs: Adaption of current thermal technologies to biomass
  - Accept a large variation in biomass fuel type and fuel pellet particle sizes
  - Facilitate fast shifts between different wood and straw fuel types and fossil fuels
  - Ensure high plant availability and high electrical efficiency when using biomass fuels
- Long term needs: Novel technologies
  - Adapt to large changes in electricity output on short timescales

Acknowledgements

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